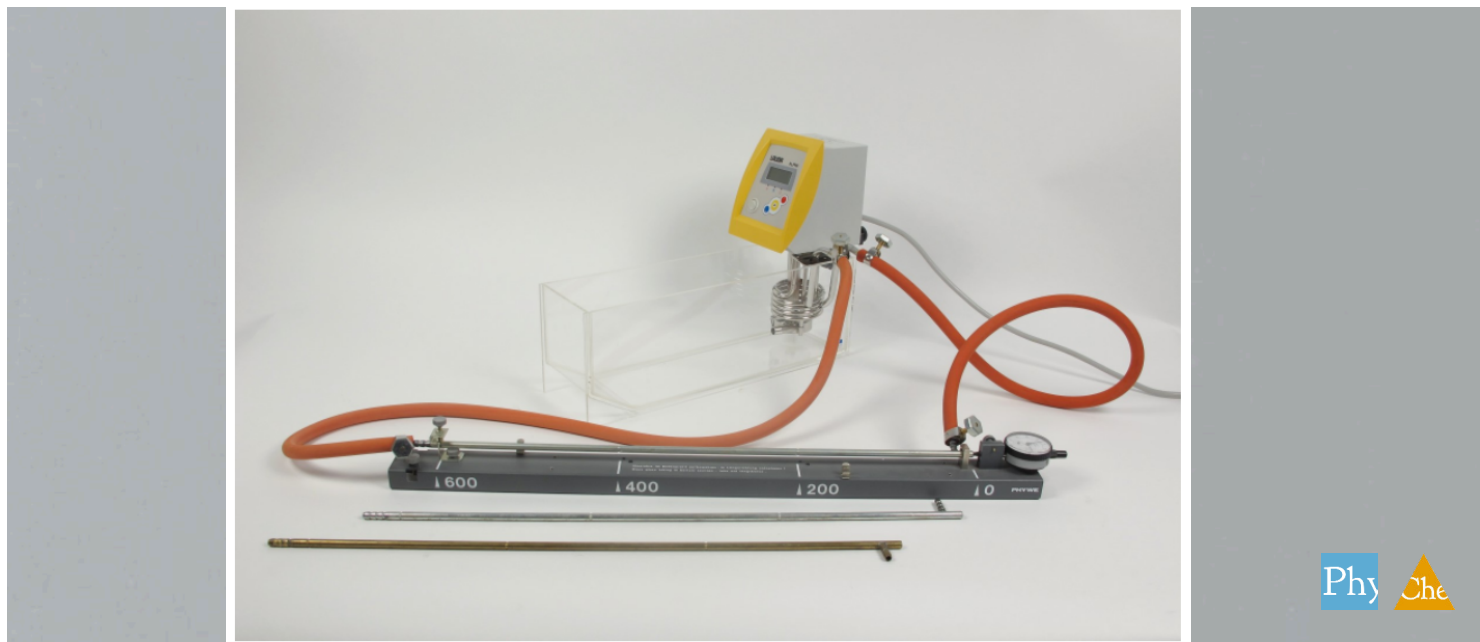


# Thermal expansion in solids and liquids



Physics

Thermodynamics

Temperature &amp; Heat

Chemistry

Physical chemistry

Thermochemistry, calorimetry

Applied Science

Engineering

Materials Science

Thermal &amp; Electrical Properties



Difficulty level

hard



Group size

2



Preparation time

10 minutes



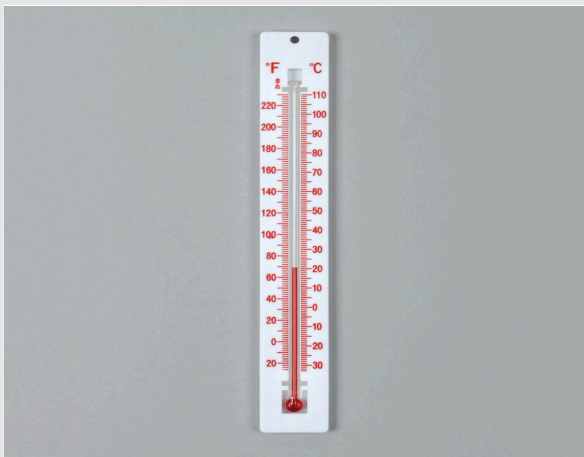
Execution time

30 minutes

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## General information

## Application

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A mercury thermometer

The expansion and contraction of materials must be considered when designing structures or mechanical applications, because a change in weather or surrounding temperature may lead to defects, malfunctions or even severe accidents.

For examples, this principle is really important in railways and aircrafts designing, bridges building, riveting of two metals, liquid thermometer and many more.

## Other information (1/2)

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### Prior knowledge



In a solid or liquid, there is a dynamic balance between the cohesive forces holding the atoms or molecules together and the conditions created by temperature. Different materials have different bonding forces between the atoms.

### Scientific principle



The volume expansion of liquids and the linear expansion of various materials is determined as a function of temperature.

## Other information (2/2)

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### Learning objective



To learn about the thermal expansion in solids and liquids.

### Tasks



1. To determine the volume expansion of ethyl acetate ( $C_4H_8O_2$ ), methylated spirit, olive oil, glycerol and water as a function of temperature, using the pycnometer.
2. To determine the linear expansion of brass, iron, copper, aluminium, duran glass and quartz glass as a function of temperature using a dilatometer.
3. To investigate the relationship between change in length and overall length in the case of aluminium.

## Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

For H- and P-phrases please consult the safety data sheet of the respective chemical.

### Ethyl acetate

H225: Highly flammable liquid and vapour.

H319: Causes serious eye irritation.

H336: May cause drowsiness or dizziness.

EUH066: Repeated exposure may cause skin dryness or cracking.

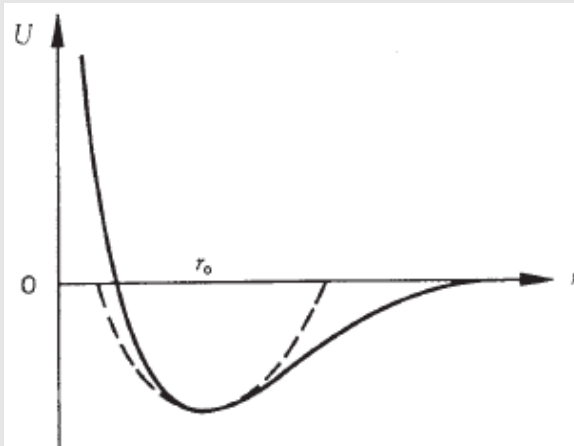
P210: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.

## Theory (1/4)

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An increase in temperature  $T$  causes the vibrational amplitude of the atoms in the crystal lattice of the solid to increase. The potential curve of the bonding forces corresponds only to a first approximation to the parabola of a harmonic oscillation (dotted line); generally it is flatter in the case of large interatomic distances than in the case of small ones.

If the vibrational amplitude is large, the centre of oscillation thus moves to larger interatomic distances. The average spacing between the atoms increases, as well as the total volume  $V$  (at constant pressure  $p$ ).



Potential curve as a function of the interatomic spacing  $r$

## Theory (2/4)

$$\alpha = \frac{1}{V} \left( \frac{\partial V}{\partial T} \right)_p$$

is called the volume expansion coefficient; if only one dimension is considered, the coefficient of linear expansion can be defined by

$$\alpha_1 = \frac{1}{l} \left( \frac{\partial l}{\partial T} \right)_p$$

where  $l$  is the total length of the body.

## Theory (3/4)

Since the changes in length

$$\Delta l = l - l_0$$

are small compared with the original length  $l_0$

$$\alpha_1 = \frac{\Delta l}{l_0} \left( \frac{l}{\Delta \theta} \right)$$

and thus

$$l = l_0 [1 + \alpha_1 (\theta - \theta_0)]$$

where  $\theta_0$  is the initial temperature.

## Theory (4/4)

**Note:** The Grüneisen equation

$$\frac{\alpha}{C_p} = \gamma \left( \frac{\kappa}{V} \right)$$

where

$$\kappa = -\frac{1}{V} \left( \frac{\partial V}{\partial p} \right)_T$$

is the compressibility and

$$C_p = \left( \frac{\partial U}{\partial T} \right)_p$$

is the thermal capacity of the solid ( $U$  = internal energy), signifies a relationship between the mechanical and thermal properties of a solid.

The Grüneisen parameter  $\gamma$  is defined by the change in the frequency  $\nu$  of lattice vibration with volume:

$$\frac{\Delta \nu}{\nu} = -\gamma \frac{\Delta V}{V}$$

and can be calculated from macroscopic quantities.

## Equipment

Position	Material	Item No.	Quantity
1	Dilatometer with clock gauge	04233-00	1
2	Tube, quartz for dilatometer	04231-07	1
3	Immersion thermostat Alpha A, 230 V	08493-93	1
4	External circulation set for thermostat Alpha A	08493-02	1
5	Bath for thermostat, makrolon	08487-02	1
6	Lab thermometer, -10..+110 °C	38056-00	1
7	Rubber tubing, i.d. 6 mm	39282-00	2
8	Syringe 1ml, Luer, 100 pcs	02593-10	1
9	Cannula 0.6x60 mm, Luer, 20 pcs	02599-10	1
10	Measuring tube, l = 300 mm, IGJ 19/26	03024-00	2
11	Wash bottle, 250 ml, plastic	33930-00	1
12	Flat bottom flask, 100ml, IGJ 19/26	35811-01	2
13	Beaker, Borosilicate, tall form, 100 ml	46026-00	1
14	Ethyl acetate 250 ml	30075-25	1
15	Glycerol, 250 ml	30084-25	1
16	Olive oil, pure 100 ml	30177-10	2
17	Hose clamp for 8-12 mm diameter	41000-00	4
18	Rubber tubing, i.d. 10 mm	39290-00	1
19	Tubing connector, ID 6-10mm	47516-01	2

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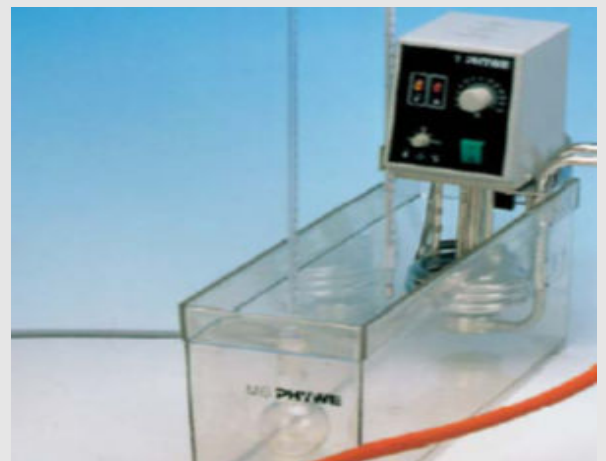
## Setup and procedure

### Setup (1/2)

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#### Experiment for volume thermal expansion

The volume of the pycnometer is determined and the scale calibrated by weighing it empty and then filled with distilled water. The pycnometer, filled with the liquid to be measured, is brought to temperature in the water bath (thermostat).



Experimental set-up for measuring thermal expansion

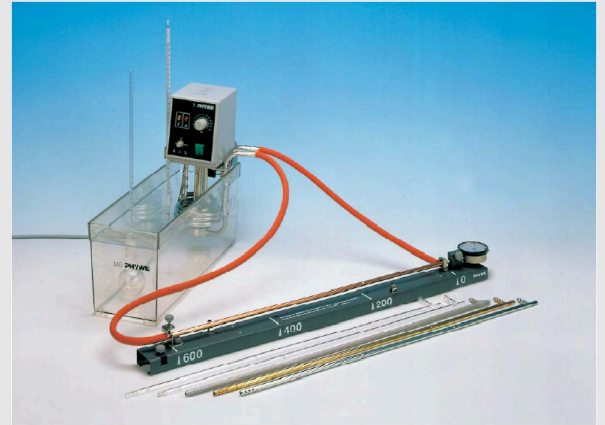


## Setup (2/2)

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### Experiment for linear thermal expansion / Experiment for linear dimensional change

The connecting tube to the thermostat is removed and the dilatometer is connected to the water circuit instead. Keep the feed and discharge lines as far away from the dilatometer as possible so that its body will not heat up.



The dilatometer is connected to the water circuit

## Procedure

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### Experiment for volume thermal expansion

The change in volume is read from the scale on the tube built into its stopper.

### Experiment for linear thermal expansion

Clamp on the measuring tube, set the scale on the dial gauge to "0" and measure the expansion as a function of the temperature. There is so little expansion in the case of duran glass and quartz glass that the heating and expansion of the dilatometer body as a result of radiation and conduction falsifies the measurement considerably. In this case, therefore, the measurement is started at the highest temperature (80 °C) and the hot water in the bath replaced with cold tap water.

### Experiment for linear dimensional change

In the case of aluminium, expansion is measured at three different rod lengths. The rod can be clamped in various places for this.

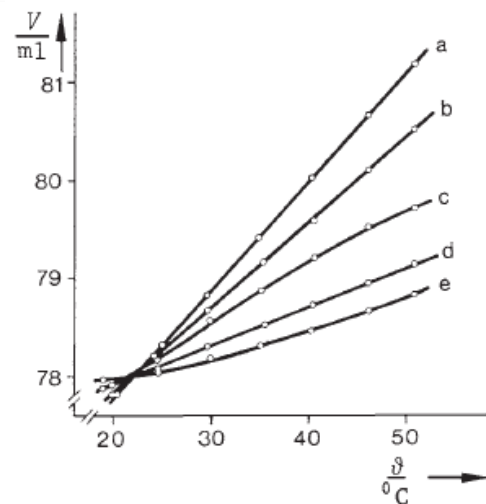
## Evaluation (1/5)

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### Experiment for volume thermal expansion

Materials	$\alpha/10^{-3} K^{-1}$
a Ethyl acetate	1.37
b Methylated spirit	1.11
c Olive oil	0.72
d Glycerol	0.50
e Water	0.20

Measured coefficient of volume expansion



Relationship between volume  $V$  and temperature  $\theta$

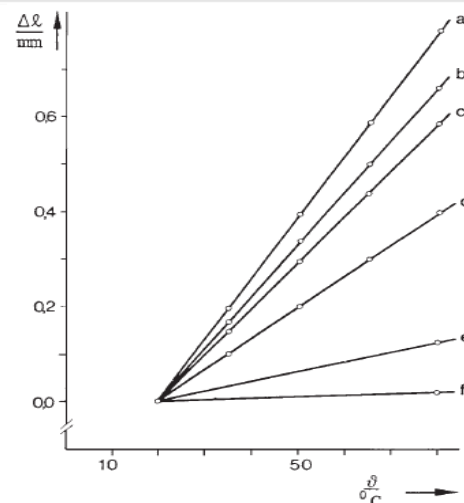
## Evaluation (2/5)

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### Experiment for linear thermal expansion

Materials	$\alpha/10^{-3} K^{-1}$
a Aluminium	2.2
b Brass	1.8
c Copper	1.6
d Steel	1.1
e Duran glass	0.32
f Quartz glass	0.046

Measured coefficients of linear expansion



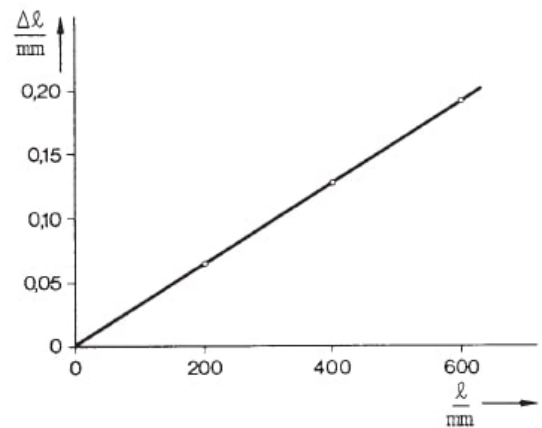
Relationship between length  $l$  and temperature  $\theta$

## Evaluation (3/5)

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### Experiment for linear dimensional change

If the temperature changes  $\Delta\theta$  are not too large, the change in length  $\Delta l$  is proportional to the original length  $l_0$



Change in length  $\Delta l$  as a function of the original length  $l_0$  for aluminium

## Evaluation (4/5)

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Describe about the thermal expansion:

In general, thermal expansion is the tendency of matter to change in volume in response to  alterations, which can be described by the volume . It describes a fractional change in length or volume per unit temperature change. Thermal expansion generally  with increasing bond energy, which also has an effect on the melting point of solids. So,  melting point materials are more likely to have  thermal expansion.





 Check

## Evaluation (5/5)

Which statements are correct to explain thermal expansion of solid?

- Volumetric expansion coefficient is usually used in describing the expansion of solid
- The thermal stress of solid is proportional to the change in temperature
- The expansion of solid is uniform in all dimensions for an isotropic material
- Thermal expansion generally decrease with increasing bond energy

✓ Check

Slide	Score/Total
Slide 18: Thermal expansion expansion	0/5
Slide 19: Thermal expansion of solid	0/3

Total Score  0/8

 Show solutions

 Retry